MECHANICAL ENGINEERING STUDENT SEMINAR

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Exploring Nanofluidic Structures with Ion Selectivity: Advancing Electrically Driven Ion Transport and Molecule Manipulation

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This research aims to study the fundamental mechanisms governing electrically driven ion transport and molecule manipulation through nanofluidic structures and their micro-sized surroundings. Such interplay of electrokinetics and micro/nanofluidics reveals remarkably rich physical phenomena, such as ion perm-selectivity, that can be harnessed for various cutting-edge applications. As demonstrated in our study, these range from lab-on-a-chip devices facilitating highly sensitive molecule analysis to ionic computation that bridges biological systems and solid-state electronics.

In the research, we employ deformable fluidic channels to reversibly tune the physical dimensions of the system from micro- to nano-size. This enables us to achieve various response regimes, ranging from low to high ion-permselectivity. Our findings demonstrate robustness and effectiveness in controlling the induction of electric field gradients and associated electrophoretic force in the vicinity of the nanofluidic structures. Introducing counteracting advection to balance the electrophoretic forces establishes a highly controlled field-gradient focusing mechanism of charged (bio)particles. We experimentally demonstrate that various analytes (e.g., charged molecules, proteins, and bacteria) can be locally accumulated into a plug-like region, reaching a pre-concentration factor of up to 1000 times compared to their initial concentration. Such capabilities offer a robust and simple means of implementing new functionalities into lab-on-a-chip devices, e.g., dynamic control over multiple preconcentrated molecule plugs, multiplex enhanced sensing, and charged-based filtration.

Additionally, asymmetric ion transport through nanofluidic structures is examined for on-chip ionic computation circuits and related applications. These ionic circuits made of various iontronic components (e.g. nanofluidic diodes and memristors) are analogous to solid-state electronic circuits, with ions serving as charge carriers instead of electrons/holes. Nevertheless, there are fundamental differences between fluidic and solid-state devices due to the complexity of ion transport. In our research, we examine these complex differences, including the significantly lowered mobility of ions compared to electrons, the variety of ionic species, the absence of ionic charge recombination, and the effect of fluid flow. Our findings exhibit unique properties enabling a diverse variety of applications, including ion separation and gating. Inspired by electronic circuits, our study has tremendous potential in effecting future research with an expected increase in functionality and integration level.

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